JEE Journal of Ecological Engineering

Journal of Ecological Engineering, 25(12), 213–222
https://doi.org/10.12911/22998993/194398
ISSN 2299–8993, License CC-BY 4.0

Received: 2024.09.26
Accepted: 2024.10.20
Published: 2024.11.01

Monitoring and Construction of Urban Noise Map to Prevent Sound Pollution

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ABSTRACT

In this work, the authors conducted a study of urban noise, using control measurements of noise levels on the example of the megacity of Almaty (Republic of Kazakhstan). Based on the experimental data obtained, a noise map was developed. The authors made measurements on four main streets at certain points and at certain times. Also measurements were made at intersections with traffic lights, taking into account the phases of signals (red or green). All the obtained data after processing were mapped using a color scheme. As a result, an experimental noise map of the Bostandyk district of Almaty was created. For the first time in Almaty, the noise map for selected neighborhoods of this district was made at different time intervals (9:00, 16:00, 19:00, 23:00) in accordance with the recommendations on monitoring and creation of noise maps. Sound pressure levels in relation to traffic signals at night and during peak hours were investigated. The results of the study confirmed that the noise levels during daytime exceed the regulatory limit. This work is devoted to the research and improvement of noise pollution mapping and monitoring system in urban environments.

Keywords: urban noise, sound pollution, noise level, monitoring, noise map.

INTRODUCTION

World Health Organization has defined noise pollution as an underestimated threat. Noise is gradually becoming an environmental and social problem, a serious threat to population's life quality. Over the past thirty years, noise levels in all urban areas have rapidly increased. There is ample evidence that city dwellers perceive noise as an inevitable part of our lives [Podawca and Karpiński, 2021].

Noise is a sound wave, usually aperiodic with a random and indeterminate pitch that degrades the quality or detects other signals. Nonetheless, noise is an unusual sound considered to be hazardous to the environment that affects human health and aquatic environment due to frequent exposure to high levels [Masum et al., 2021].

It is known how natural environment uproar favorably affects the human body (sound of leaves, rain, rivers etc.). As statistics show, people who work by the river, at the sea, in the forest have diseases of the nervous, cardiovascular system much less frequently than individuals working in the city. It has been proven that the singing of birds, rustling of leaves, sounds of rain, murmur of a stream has beneficial effect and heal the nervous system, and under the influence of sounds of a waterfall, muscle work begins to augment. It has been known for a long time how the sound of harmonious music has a positive effect, when lullabies (quiet, gentle monotonous tunes) were sung before going to bed, the sound and tunes of which not only soothed, but also lulled.

Based on research results as well as the practice shows, in big cities, more than 70% of citizens suffer from noise. According to some data, people living near the main highways and industrial zones have an average biological age of 7 years older than people living in the quiet “sleeping areas”.

Plenty of studies are devoted to the issue of noise impact from vehicles on life quality and people’s mental health. So, at a noise level above 65 dBA, heart rhythm can be disturbed and pulse increased, noise at 85 dBA can cause tachycardia and malfunction of gastrointestinal tract [Pretzsch et al., 2021; Fan et al., 2022]. Unfavorably affect suddenly occurring, intermittent noise, especially in the evening and at night [Vaverková et al., 2021]. During the sleep, such noises cause strong fright, especially in children. Under the influence of noise at 50 dBA, sleep becomes superficial, after waking up, people feel tired and have a headache, heart palpitations [Liang et al., 2024; Heidari et al., 2021]. The shortage of rest after a hard day leads to the fact that a person’s fatigue does not disappear, but passes into a chronic stage, which contributes to the growth of a number of diseases, such as central nervous system disorders, hypertension etc [Yu et al., 2022].

At noise levels above 80 dBA and increasing it on each 1–2 dBA causes a decrease in labor productivity by at least 1% [Abikenova et al., 2023]. Economic losses from the increased noise in developed countries reach tens of billions of dollars a year. Today, competitiveness of machines is largely determined by their noise level. Concurrently, the less noise machine, unit, installation produces usually much more expensive it is. The reduction in sound level by 1 dBA provides approximately 1% increase in the cost of the sold product. In modern aircraft, the cost of noise protection reaches 25% of the product cost, and in cars – 10%. The problem of combating the noise is the most significant problem related to environment improvement. In line with some reports, over 60% of large cities’ population live in conditions of excessive noise. Pursuant to the subjective sense of loudness, urban noise most often exceeds admissible values by 2–4 times [Yadav et al., 2024].

High level of motorization increased traffic on the main roads of cities, growth of railroad networks increased acoustic discomfort and air pollution level in the urban area.

Permissible levels of internal noise of vehicles are presented in Table 1.

Individual cars and large traffic flows in the main streets create very high noise level, as the share of main streets is 60–70% of the city street network’s total length and 80–90% of the cars’ length. Traffic flows on the main roads can be considered as the main source of noise in cities. They account for the largest number of complaints (up to 65–80%) submitted to sanitary-epidemiological stations. All these make unfavorable close neighborhood of transport with residential area and people living in it. Therefore, when establishing the city’s general plan, the task arises to

Table 1. Permissible levels of motor vehicles’ internal noise

Motor vehicle	Permissible sound level, dBA
Cars and buses for transporting the passengers	
Category M1 (except wagon or semi-bonnet body layout)	78
Category M1 (wagon or semi-bonnet body layout)	80
Category M2 M3 (except for the location of the engine in front of or next to the driver’s seat): - at the driver’s seat - in the passenger area of buses of class 2 and 3 according to state standard 27815 - in the passenger area of class 1 buses	 78 80 82
Categories M2 M3 (with the engine in front of or next to the driver’s seat): - at the driver’s workplace and in the passenger room	 80
Vehicles for transporting the goods	
Category N1 with GVW up to 2 t	80
Category N1 with gross weight from 2 t to 3.5	82
Category N2 N3 except for those intended for international and intercity transportation	82
Category N2 N3 intended for international and intercity transportation	80
Semi-trailers designed for the transport of passengers	80
Trolleybuses - at the driver’s seat - passenger area	 78 82

determine existing or expected calculated sound levels on major roads of the entire city road network, as well as industrial and municipal enterprises, airport, railways and other noise sources [Zubala and Sadurska, 2016].

The chosen research topic is relevant, since noise is one of the main urban problems of the modern world. By not solving and avoiding the noise problem, we can increase number of deaf people, so in the near future we will face the fight against noise as we once experienced cholera and plague.

METHODS AND METHODOLOGY

Making the noise level measurements

Noise map of Almaty city, namely Bostandyk district was created. At the same time noise measurements were carried out in Abay - Satbayev - Baitursynov - Massanchi. Measurements were carried out in accordance with the requirements of State standard 20444-2014 NOISE. Transport streams. Methods for determining the noise characteristic [State standatd, 2014].

Measurements were executed by OCTAVA-101A sound level analyzer, which is designed to measure the root meant square, equivalent and peak sound levels, sound pressure levels (SPL) in octave and one-third octave bands with the purpose to assess the effect of sound and infrasound on a person at work and in residential, public buildings, the definition of the acoustic characteristics of machinery and machines [Utepov et al., 2019], as well as scientific research [Utepov et al., 2017].

The sound level meter has: measuring and indicating unit (IMU), KMM400 microphone preamplifier with VMK-205 microphone capsule and a power supply.

Preparing the device for work. VMK-205 microphone capsule was screwed onto KMM400 preamplifier. We inserted KMM400 preamplifier into the input connector of OCTAVA-101A device (5-pin switch craft connector on the conical part). All operations on connecting/disconnecting the microphone and preamplifier were carried out with the device turned off.

Measurements were carried out to assess the actual noise characteristics of traffic flows, consisting of cars and trucks, road trains, buses, trolleybuses, trams, motor vehicles (motorcycles, scooters, mopeds, motorbikes) at the given points on the streets shown in Figures 1–4. Places for measuring the noise characteristics of motor traffic flows were chosen on straight sections of streets and highways with vehicles' steady speed.

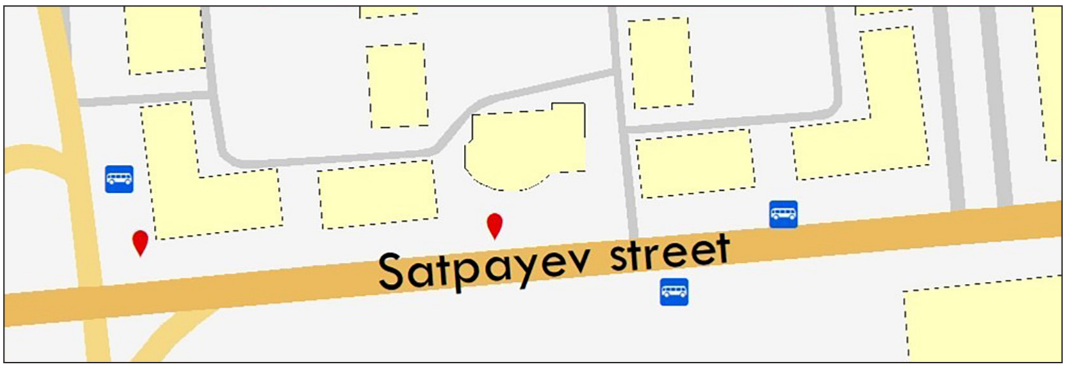

Figure 1. Measurement points in Satbayev street

Figure 2. Measurement points on Abay avenue

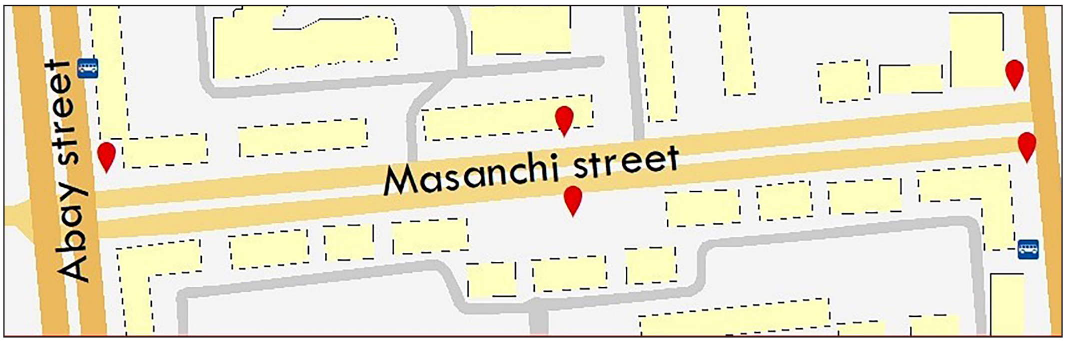

Figure 3. Measurement points in Massanchi street

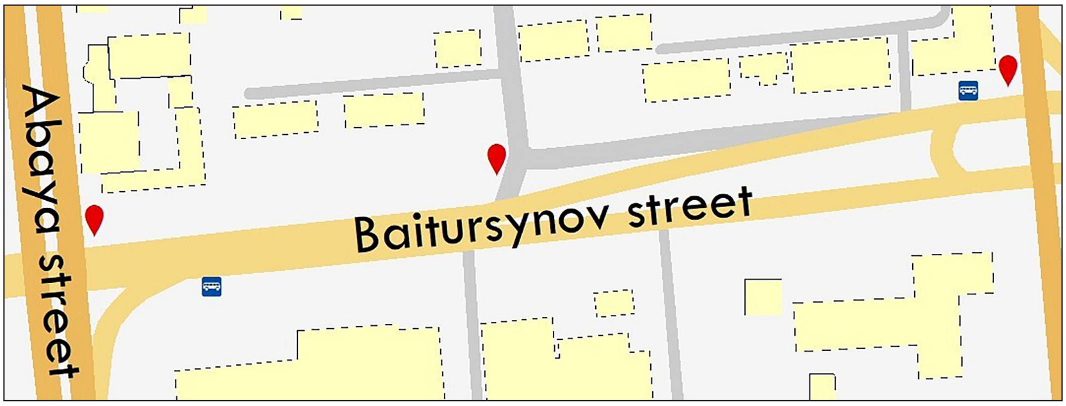

Figure 4. Measurement points in Baitursynov street

Noise characteristics of traffic flows are the main initial data for performing acoustic calculations based on current regulatory and technical documents to assess the noise regime in the premises of residential and public buildings and in residential areas adjacent to the road network of cities and other settlements, to automobile and railway roads, as well as to open subway lines.

Main noise characteristics of traffic flows are the equivalent and maximum sound levels, dBA during the day (from 7.00.a.m. to 23.00. p.m.) and at night (from 23.00. p.m. to 7.00. a.m.) time.

Additional noise characteristics of traffic flows, determined if necessary, are equivalent sound pressure levels, dB, in octave bands with geometric mean frequencies in the range from 31.5 to 8000 Hz according to State standard 12090.

The first measurements were made on March 21, during the daytime and at night, at 10:00 a.m. and 17:00 p.m., the last on April 25 at 9:00 a.m., 16:00 p.m., 19:00 p.m. and 00:00 a.m.

Measurement period duration for the noise characteristics of the traffic flow, which may include vehicles of various types (in particular, cars and trucks, public transport), depends on traffic intensity. Measurement is continued until the readings of the measuring instrument stabilize within the selected measurement accuracy, which should be not less than ± 0.5 dBA, but measurement duration should be at least 5 minutes.

Methodology for constructing the noise map

Procedure for constructing noise map in the general case obeys the following algorithm:
- collection of data on noise sources;
- building a terrain model for the city area under study (buildings, relief, landscape etc.);
- construction on the terrain model of the noise field (fields) generated by technogenic sources;
- analysis of the received data;
- design of noise protection means;
- modeling, determination of effectiveness of the developed means of protection.

Thus, noise maps are an effective tool in developing and implementing the noise protection measures, since they allow to:
- select points for acoustic monitoring and conduct acoustic monitoring;

- assess noise levels anywhere in the city when designing new buildings;
- substantiate the assessment of releasing the individual territories for new construction;
- evaluate the list and evaluate the effectiveness of necessary noise protection measures and means in designing the objects for various purposes;
- conduct an acoustic assessment of the territory of residential development and an economic justification for the cost and effectiveness of protective equipment necessary to ensure acoustic comfort;
- simulate the change in acoustic impact on the population when man-made objects peculiarities change.

Drawing up the noise maps as part of projects for constructing and reconstructing motor transport facilities is also one of the principal requirements of the current Building regulations 23-03-2003 "Protection from noise" [Building regulations, 2003].

When assessing the impact on the environment, building noise maps and developing environmental protection measures, modern software systems are applied, calculation of which is based on the latest regulatory documents.

Noise characteristics of Traffic flows are the main initial data for performing acoustic calculations according to the current regulatory and technical documents to assess the noise regime in premises of residential and public buildings and in residential areas adjacent to the road network of cities and other settlements, to motor and railroads, as well as to open subway lines.

Simultaneously, with measuring the traffic flow noise characteristics, durations of each measurement time interval and observation time interval should be recorded.

When measuring the noise characteristics of traffic flow, it is advisable to simultaneously determine its intensity, composition and speed.

Traffic flow intensity is equal to the number of vehicles passing through the cross section of the road in both directions per unit of time.

Before and after each series of measurements of traffic flows' noise characteristics, it is necessary to check the calibration of measuring instruments and make sure that measuring instruments meet the requirements given in their operation manuals and passports.

Calibration of measuring instruments of the 1st class should be carried out using an acoustic sound calibrator of the 1st class or, in case of measuring instruments of the 2nd class, using an acoustic sound calibrator of the 1st or the 2nd class.

If, during calibration before and after the measurement, the readings of the sound level meter or other recording instrument differ by more than 1 dBA, then measurements performed are invalidated, the measuring instrument is recalibrated and measurements are repeated.

Measurements should be performed on sections of streets and highways with clean and dry surface of the roadway.

The places for measuring noise characteristics of train flows, or metro trains, or trams should be selected on straight and horizontal sections of the track without wave-like wear of the rails. It is also allowed to take measurements on track's curved sections with a radius of curvature of at least 1000 m and on sections with a slope or rise, but not more than 5%.

Time of measurements should be chosen during periods of maximum traffic intensity, both in the daytime and at night.

It is advisable to measure traffic flows' noise characteristics during the daytime at least three times: in the morning in the interval from 7.00 a.m. to 9.00 p.m., in the afternoon in the interval from 9.00 a.m. to 19.00 p.m. and in the evening in the interval from 19.00 p.m. to 23.00 p.m.

During the night period it is advisable to measure traffic flows' noise characteristics twice: in the interval from 23.00 p.m. to 1.00 a.m. and in the interval from 1.00 a.m. to 7.00 a.m.

On the whole, based on the tasks set, other time intervals can be selected for measuring the traffic flows' noise characteristics.

RESULTS AND DISCUSSION

The Almaty city is rightfully considered as the city of students, and Bostandyk district can be called as its center. Almost all educational institutions are located in this area, including universities, colleges and schools. Consequently, the number of people and transport is above the norm, and that is additional noise. The city practically does not sleep, the approximate time when silence and noise level in the city does not exceed the norm is from 2.00 a.m. to 7 a.m., and on weekends until three o'clock in the morning. Morning usually begins with traffic jams, the working day begins at 9 o'clock, and all routes are directed in one direction, creating the traffic jams. The noise from cars negatively affects human in the traffic jam, or on foot while walking to the designated point. We are aware of the fact that the increased noise affects the nervous and cardiovascular system, causes irritation, fatigue, aggression and so on. Under such influence, in the entire world there are millions of working people and hundreds of millions of city residents. This is the medical aspect of noise effect on an individual. The economic aspect is the effect of noise on labor productivity.

The advantage of noise maps is their ease of perception. Color-coded zones correspond to specific levels of sound. Zoning can occur in steps of 1, 5, 10 or more dB. Zones with high noise levels usually have red and dark blue color, levels within the regulated limits – green, close to the norm and border values – yellow and orange. Thus, ease of noise maps perception allows to estimate noise levels at any point of the territory in the shortest time [Alam et al., 2020].

The noise map enables:

- assessing the territory from an acoustic point of view;
- determining the city districts' noise status;
- understanding of the most unfavorable zones (disadvantaged areas) of the city;
- finding the answers to citizens' complaints on high level of noise;
- taking decisions related to noise protection measures;
- deciding on the location of new residential buildings.

The noise map of the given section in Almaty was compiled as follows:

- the required site for study was taken from the city map;
- draw legend of the map - conventional symbol for dependence of noise level and color (1st layer);
- 2nd layer – laying the legend on the maps;
- at the measurement points, using the gradient tool, the noise level is denoted by color based on the legend.

The obtained results are presented in Figures 5–8. Transport noise is one of the main sources of noise in the city. The streets noise is created from noise of separate transport units: cars and trucks, buses and trolleybuses, motorcycles and mopeds, trams.

Car's external noise consists of several basic components: engine and housing noise, cooling fan and exhaust system, tires (a pair of carriageway – wheels), aerodynamic noise when driving.

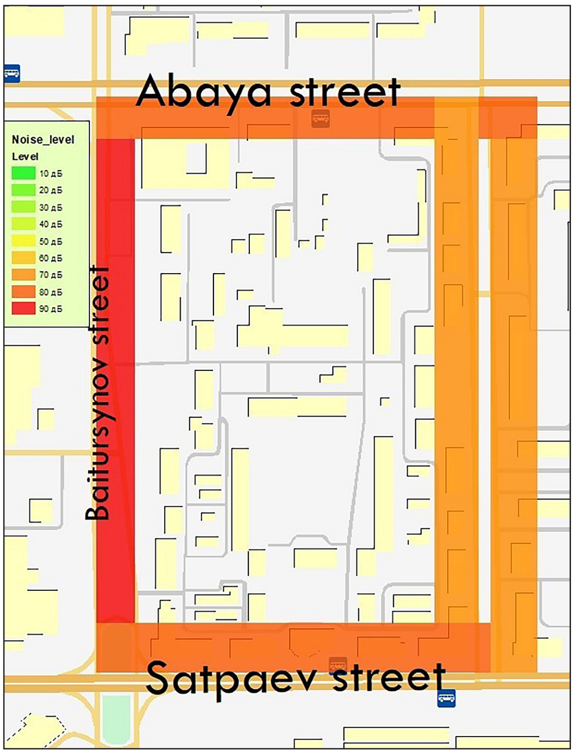

Figure 5. Noise map of the selected site at 9:00

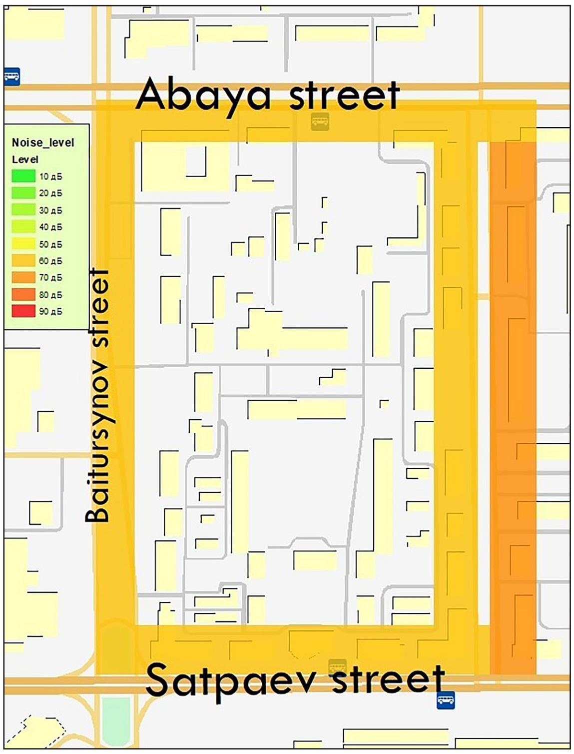

Figure 6. Noise map of the selected site at 16:00

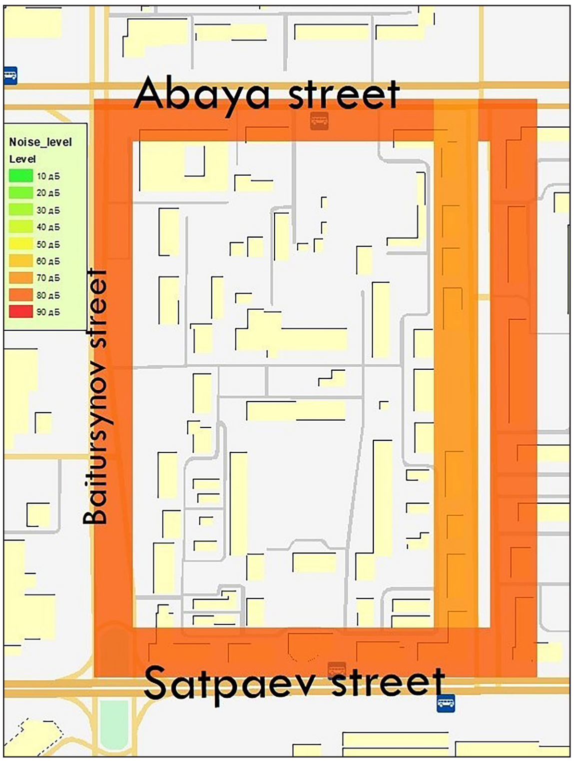

Figure 7. Noise map of the selected site at 19:00

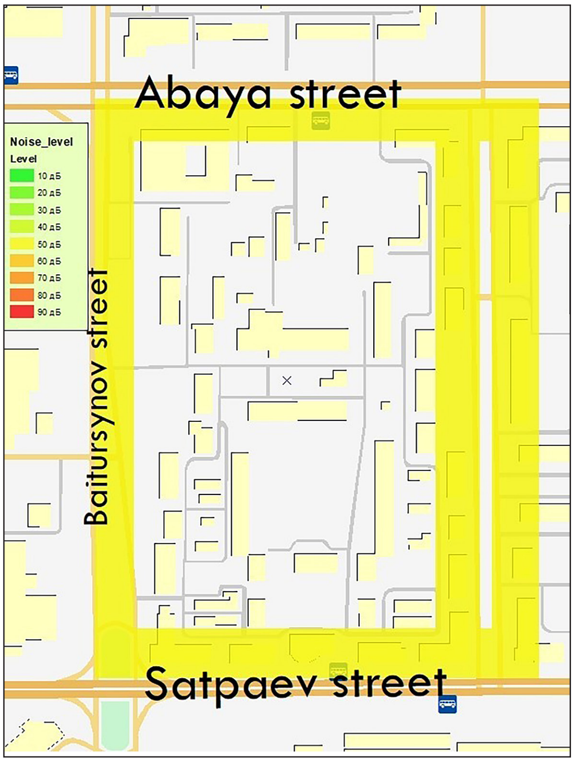

Figure 8. Noise map of the selected site at 23:00

Under certain operating conditions, each of these sources can become dominant. Non-muffled engine exhaust is the strongest noise source in a car: more than 100 dBA at 7.5 m distance when accelerated. With the increase in the degree of silencing the exhaust, the role of other noise sources increases.

The exhaust noise is not directly related to the engine power, it does not significantly depend on the load and engine speed. When the load changes, cars' sound level with a gasoline engine can be changed by 10 dBA or more, with a diesel engine - up to 4 dBA. This circumstance should be taken into account when increasing the longitudinal slope of the street roadway. Cars' external noise is directly proportional to movement speed.

Table 2 and Figure 9 demonstrate the corrected levels of transport stream sound from the time of day. As it can be seen from Table 2, maximum sound levels are in the morning (80–90 dBA) and evening (85–90 dBA), which is explained by the dense traffic flow and congestion during the peak hours. Minimum sound levels were in the afternoon (45–51 dBA) and night time (40–43 dBA) that is explained by quieter traffic and quiet noise background of the streets as a whole.

Table 2. Sound levels of transport stream from the time of day

No.	Morning (9:00)	Day (16:00)	Evening (19:00)	Night (23: 00)
1	90	60	85	53
2	85	58	79	40
3	78	61	88	45
4	80	51	83	40
5	80	60	70	50
6	58	45	69	45
7	60	71	70	43
8	85	65	89	51
9	82	60	88	50
10	78	63	90	51
11	70	60	85	55

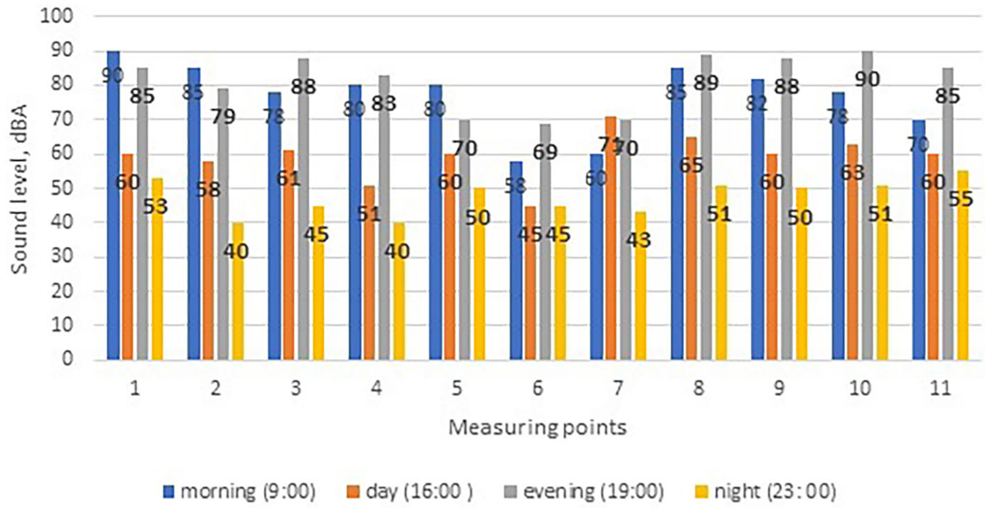

Figure 9. Sound levels in Almaty streets, Bostandyk district, depending on time of the day

However, although at this time (16.00 and 00.00) the noise does not reach high levels and meets sanitary and hygienic requirements, its impact on residents of nearby houses does not decrease. So, the increase in motor transport speed and various noise of engines of cars and trucks, road trains, buses, trolleybuses, trams and motor vehicles leads to a significant increase in the noise level in residential areas along transport lanes. Maximum sound pressure level at (7.5 ± 0.2) m distance from the axis of the nearest to the measuring point of the strip or the path of vehicles and at (1.5 ± 0.1) m altitude from the level of carriageway surface coverage reaches 90 dBA, and causes population's complaints in 70–90% of cases.

Dependence of traffic flow SPL on the traffic signal

If dependences of noise levels at given points have indicators corresponding to the time of day for measurements, then it is also necessary to consider noise characteristics depending on the traffic light signal at highway intersections.

Figure 10–11 shows noise peculiarities depending on the time of day and traffic signal color.

Maximum sound levels at rush hour are 89-90 dBA at the green traffic lights and 65–70 dBA at red. Difference of 14–20 dBA is explained by the stop of the traffic flow with engines on, which does not exclude the transport's sound levels in general. Minimum sound levels during the rush hour are

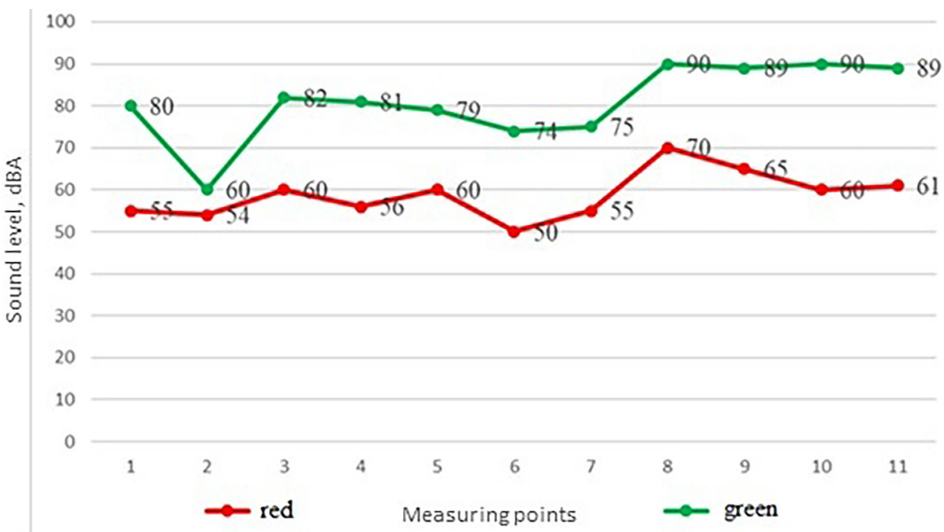

Figure 10. Sound level of traffic noise depending on the traffic signal at rush hour

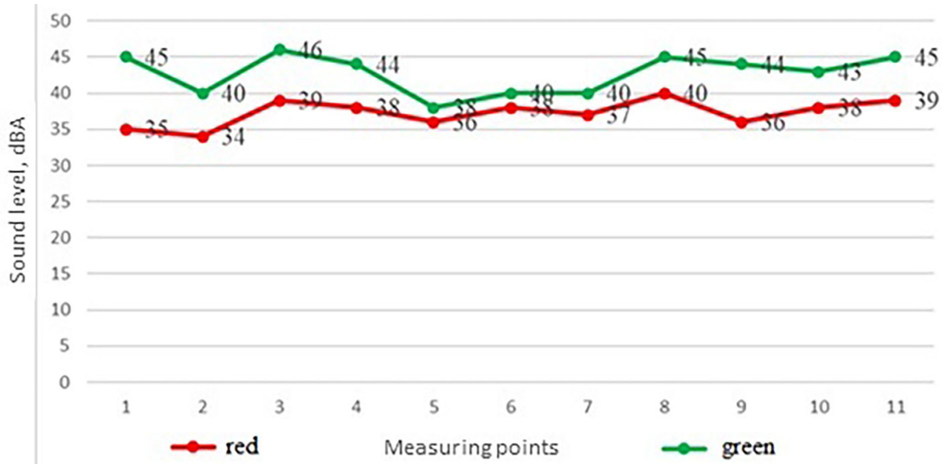

Figure 11. Sound level of traffic noise depending on the traffic light signal at rush hour at night

equal, respectively, with the green traffic light – 60–74 dBA and with the red one – 50–54 dBA.

Maximum sound levels at night are 45–46 dBA with the green traffic light and 38–40 dBA with the red one. Difference of 7–8 dBA in this case is not significantly different due to the general quiet noise background at night. Minimum sound levels at night are 38–40 dBA, respectively, for the green traffic light, and 34–35 dBA for the red one.

If we compare the sound pressure levels between measurements at night and peak hours, maximum difference at the green traffic light corresponds to 34 dBA, at the red one – 20 dBA.

CONCLUSIONS

Despite the green spaces on the streets, in the form of coniferous and deciduous trees, shrubs and lawns, the speed limit for cars is not higher than 40 km/h, and in some sections of the road not higher than 60 km/h, noise protection structures along the roads, on the largest highways and along industrial zones, the noise level is not lessened. To combat urban noise, it was proposed to develop the noise map for one of the sections of Bostandyk district in Almaty. To create the given noise map, measurements were taken in the square of Abay – Massanchi – Satbayev – Baitursynov, at certain points as well as at particular times. Measurements were also taken at sections of intersections with traffic lights, depending on the traffic light signal, red or green. All data after processing were put on the map, in colors. As a result, the experimental map of Almaty city, Bostandyk district was compiled.

Hence, for the first time in Almaty, the noise map of selected blocks of the selected noisy district was constructed at different times of the day (9.00, 16.00, 19.00, 23.00) according to all recommendations for monitoring and building the noise maps. The study was conducted related to the sound pressure levels depending on the color of the traffic signal at night and peak hours.

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